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(54) **PEN TRACKING AND LOW LATENCY DISPLAY UPDATES ON ELECTRONIC PAPER DISPLAYS**

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(52) **U.S. Cl.** **345/173**; 345/178

(58) **Field of Classification Search** 345/5–25, 345/87, 89, 105–108, 156, 169–182, 204–214, 345/626, 520, 419, 660, 690, 501, 536, 55, 345/545, 59; 455/556.1; 178/18.01–18.09, 178/19.01–19.05; 349/62
See application file for complete search history.

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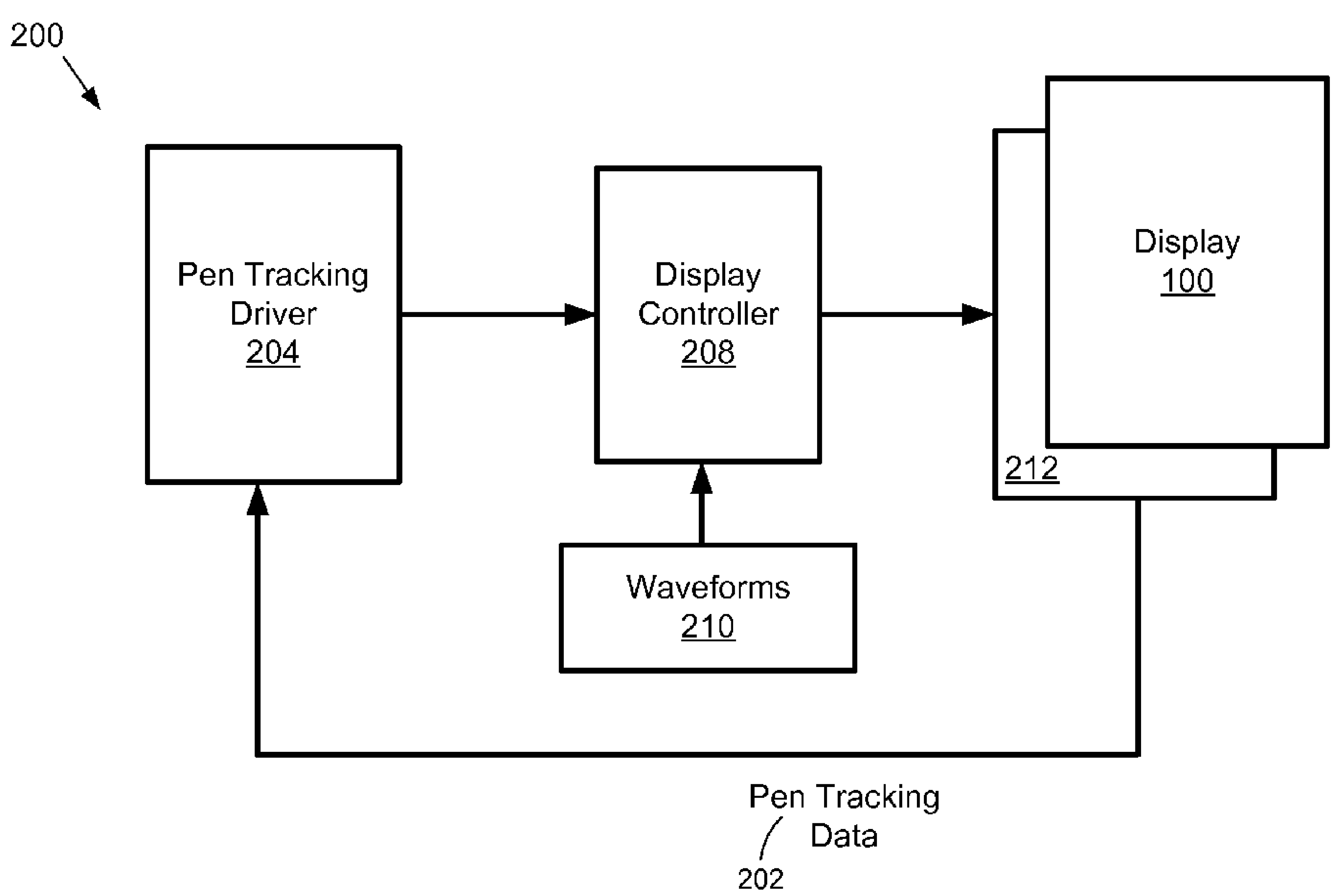
(57) **ABSTRACT**

A system and a method are disclosed for fast pen tracking a low latency display updates on an electronic paper display. Pen input information is received on an electronic paper display that updates at a predetermined display update rate. A line drawing module of the electronic paper display driver determines at least one pixel to activate based on the received pen input information. The at least one pixel is updated independent of the display update rate of the electronic paper display. Active pixel state information is maintained separately for each pixel in real time until the pixel update is complete and the pixel is deactivated. In some embodiments, a future pixel to activate is determined based on the received pen input information. The future pixel is deactivated if pen input information is not received on the activated pixel for a predetermined amount of time.

24 Claims, 7 Drawing Sheets



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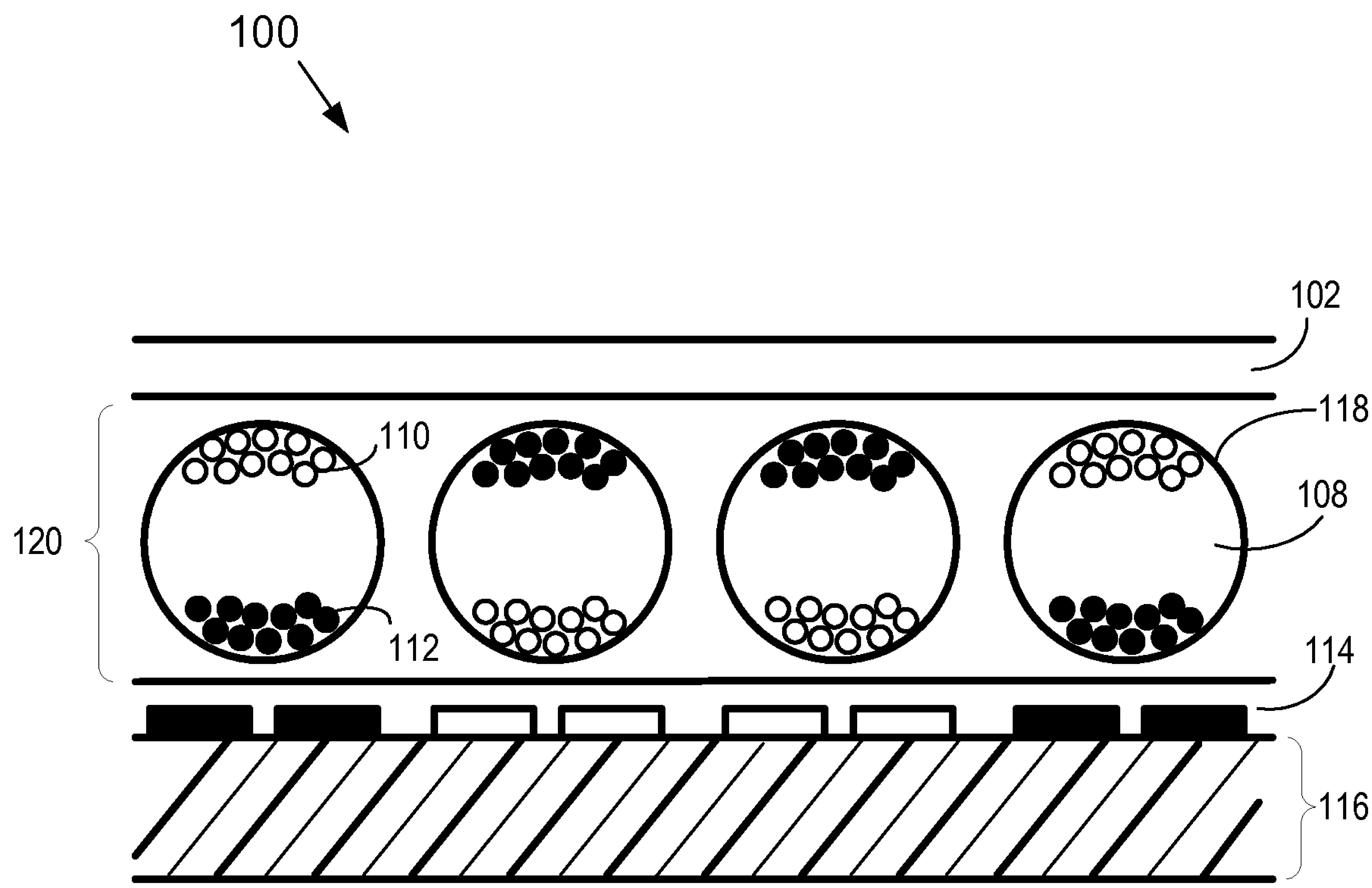

FIG. 1

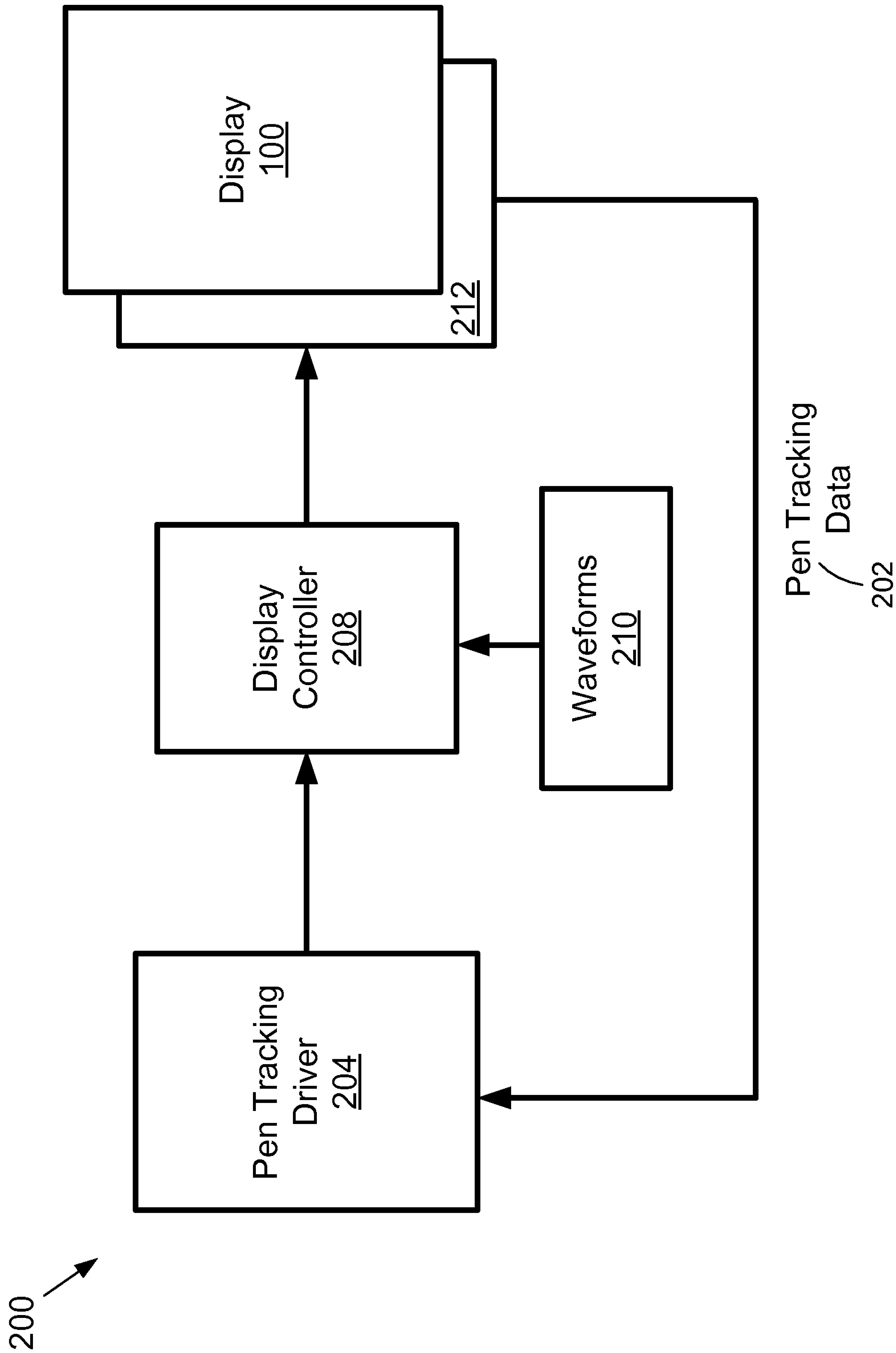
Display
100
212
Display
Controller
208
Waveforms
210
Pen Tracking
Driver
204
Pen Tracking
Data
202
200

FIG. 2

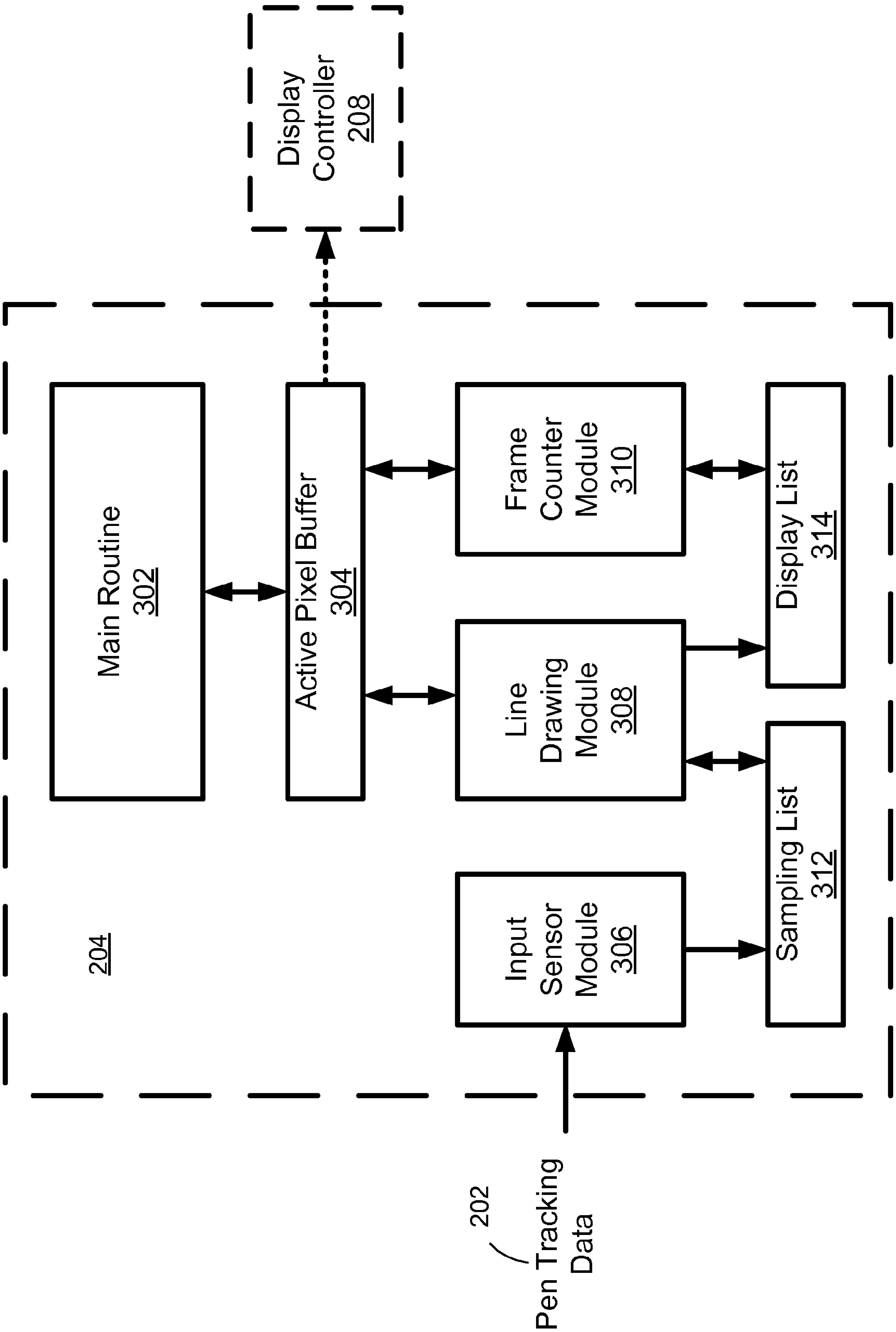
Display Controller 208
204
Main Routine 302
Active Pixel Buffer 304
Frame Counter Module 310
Line Drawing Module 308
Input Sensor Module 306
Display List 314
Sampling List 312
202
Pen Tracking Data

FIG. 3

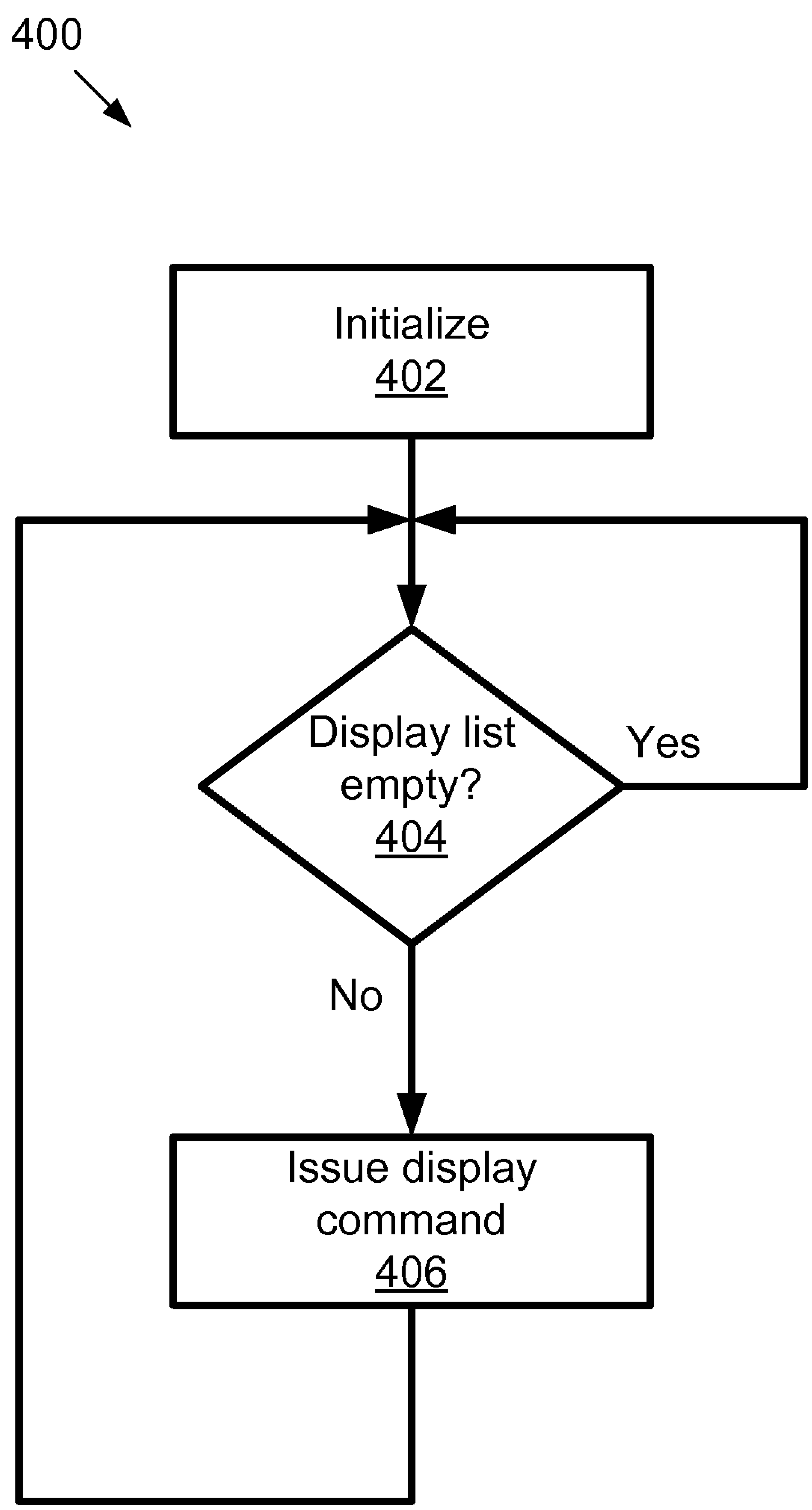
400
Initialize
402
Display list
empty?
404
Yes
No
Issue display
command
406

FIG. 4

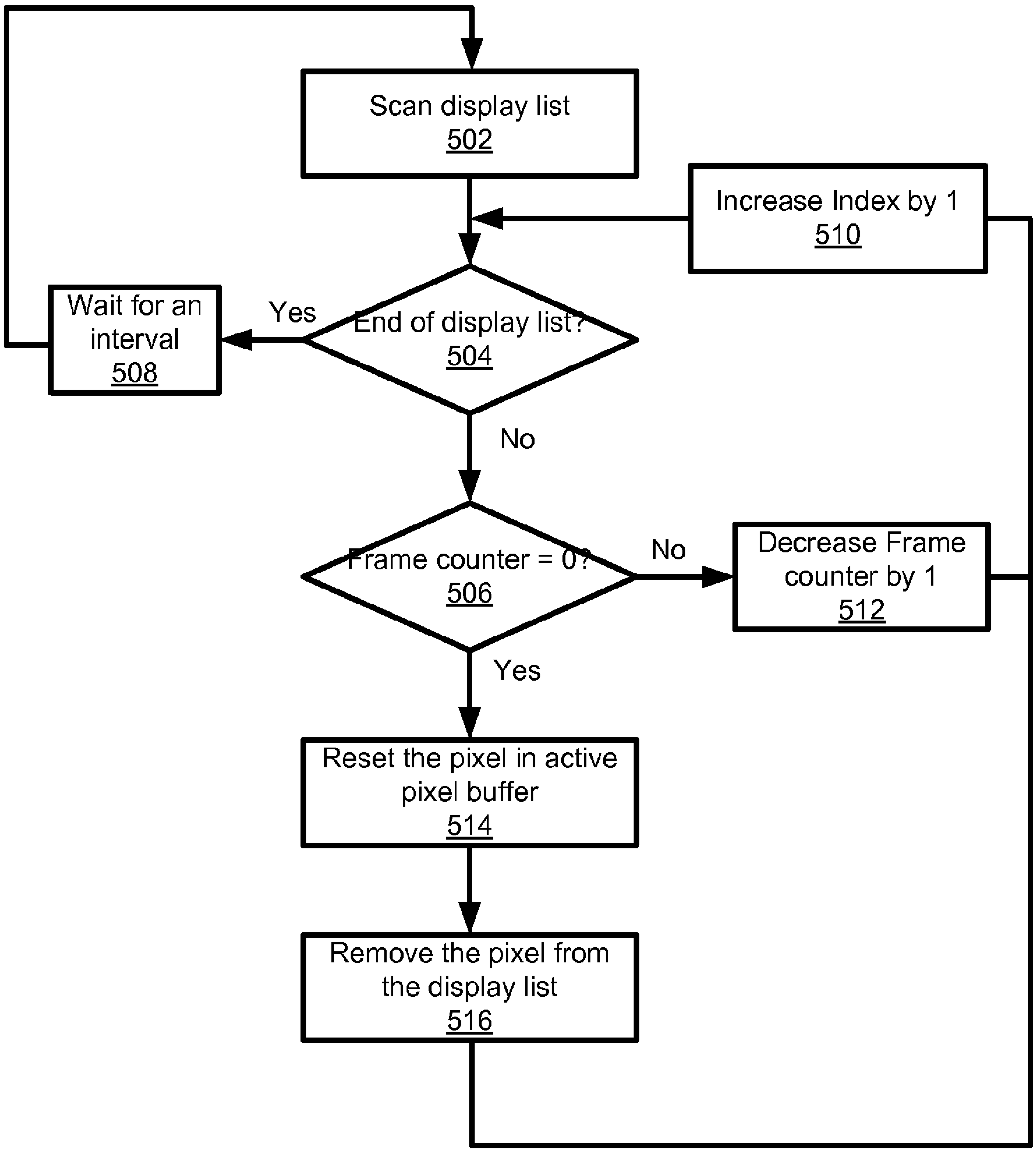
Scan display list
502
Increase Index by 1
510
Wait for an interval
508
Yes
End of display list?
504
No
Frame counter = 0?
506
No
Decrease Frame counter by 1
512
Yes
Reset the pixel in active pixel buffer
514
Remove the pixel from the display list
516

FIG. 5

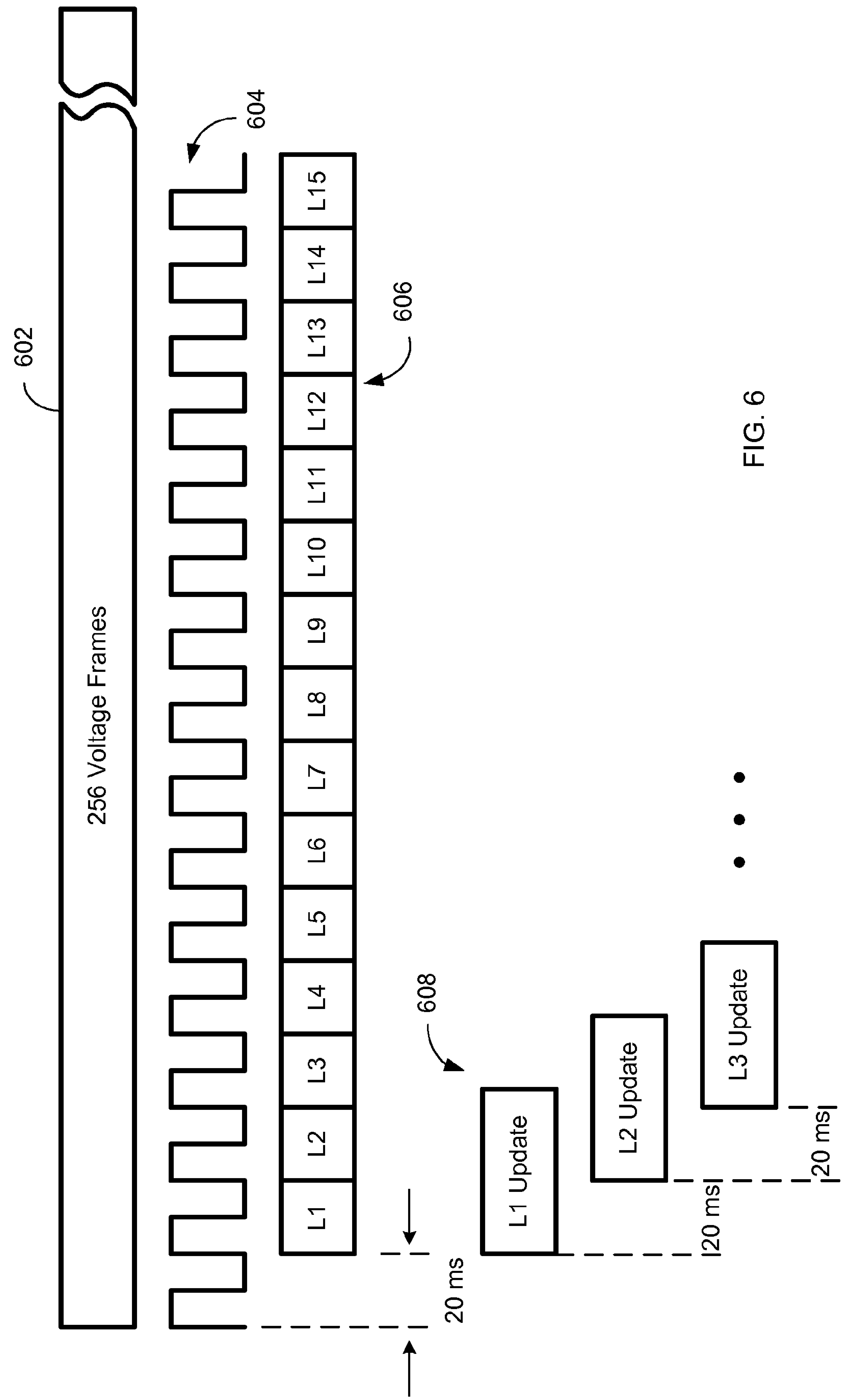
602
256 Voltage Frames
604
L1
L2
L3
L4
L5
L6
L7
L8
L9
L10
L11
L12
L13
L14
L15
606
20 ms
608
L1 Update
L2 Update
L3 Update
20 ms
20 ms

FIG. 6

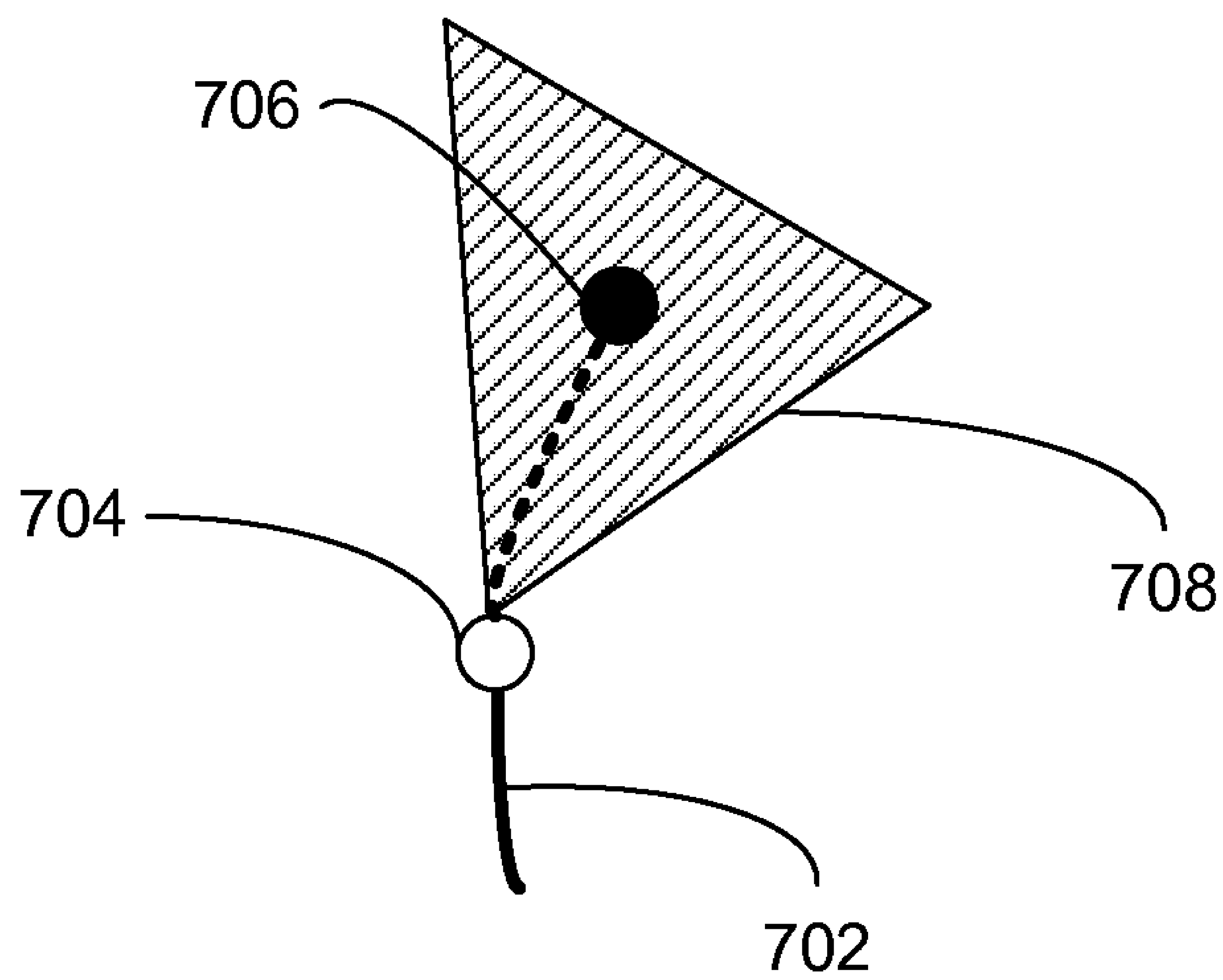

FIG. 7

PEN TRACKING AND LOW LATENCY DISPLAY UPDATES ON ELECTRONIC PAPER DISPLAYS

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Patent Application No. 60/944,415, filed Jun. 15, 2007, entitled "Systems and Methods for Improving the Display Characteristics of Electronic Paper Displays," the contents of which are hereby incorporated by reference in its entirety.

BACKGROUND

1. Field of Art

The disclosure generally relates to the field of electronic paper displays. More particularly, the invention relates to pen tracking and low latency display updates on electronic paper displays.

2. Description of the Related Art

Several technologies have been introduced recently that provide some of the properties of paper in a display that can be updated electronically. Some of the desirable properties of paper that this type of display tries to achieve include: low power consumption, flexibility, wide viewing angle, low cost, light weight, high resolution, high contrast, and readability indoors and outdoors. Because these displays attempt to mimic the characteristics of paper, these displays are referred to as electronic paper displays (EPDs) in this application. Other names for this type of display include: paper-like displays, zero power displays, e-paper, bi-stable and electrophoretic displays.

A comparison of EPDs to Cathode Ray Tube (CRT) displays or Liquid Crystal Displays (LCDs) reveal that in general, EPDs require less power and have higher spatial resolution; but have the disadvantages of slower update rates, less accurate gray level control, and lower color resolution. Many electronic paper displays are currently only grayscale devices. Color devices are becoming available although often through the addition of a color filter, which tends to reduce the spatial resolution and the contrast.

Electronic Paper Displays are typically reflective rather than transmissive. Thus they are able to use ambient light rather than requiring a lighting source in the device. This allows EPDs to maintain an image without using power. They are sometimes referred to as "bi-stable" because black or white pixels can be displayed continuously and power is only needed to change from one state to another. However, some devices are stable at multiple states and thus support multiple gray levels without power consumption.

While electronic paper displays have many benefits, a problem is that most EPD technologies require a relatively long time to update the image as compared with conventional CRT or LCD displays. A typical LCD takes approximately 5 milliseconds to change to the correct value, supporting frame rates of up to 200 frames per second (the achievable frame rate is typically limited by the ability of the display driver electronics to modify all the pixels in the display). In contrast, many electronic paper displays, e.g. the E Ink displays, take on the order of 300-1000 milliseconds to change a pixel value from white to black. While this update time is generally sufficient for the page turning needed by electronic books, it is problematic for interactive applications like pen tracking, user interfaces, and the display of video.

One type of EPD called a microencapsulated electrophoretic (MEP) display moves hundreds of particles through a viscous fluid to update a single pixel. The viscous fluid limits the movement of the particles when no electric field is applied and gives the EPD its property of being able to retain an image without power. This fluid also restricts the particle movement when an electric field is applied and causes the display to be very slow to update compared to other types of displays.

When displaying a video or animation, each pixel should ideally be at the desired reflectance for the duration of the video frame, i.e. until the next requested reflectance is received. However, every display exhibits some latency between the request for a particular reflectance and the time when that reflectance is achieved. If a video is running at 10 frames per second and the time required to change a pixel is 10 milliseconds, the pixel will display the correct reflectance for 90 milliseconds and the effect will be as desired. If it takes 100 milliseconds to change the pixel, it will be time to change the pixel to another reflectance just as the pixel achieves the correct reflectance of the prior frame. Finally, if it takes 200 milliseconds for the pixel to change, the pixel will never have the correct reflectance except in the circumstance where the pixel was very near the correct reflectance already, i.e. slowly changing imagery.

In some electronic paper displays, annotation is possible by adding an input sensor layer on top of or underneath the display. These types of electronic paper displays work like a writing tablet. A pen or a stylus is used to activate the pixels on writing surface of the electronic paper display, thus acting like a pen or pencil writing or making annotations on a piece of paper. However, because of the limited speed at which the image can be updated, the EPDs are not effective at showing pen tracking in real time. The key requirements of pen tracking are update speed and contrast, which generally conflict with each other on electronic paper displays. For instance, drawing a light gray line takes shorter time than drawing a black line on some EPDs.

It would therefore be highly desirable to enable both high speed and high contrast on current electronic paper displays, thus allowing for real-time pen tracking.

SUMMARY

The present invention overcomes the deficiencies and limitation of the prior art by providing a system and method for fast pen tracking and low latency display updates on an electronic paper display.

Pen input information is received on an electronic paper display that updates at a predetermined display update rate. A line drawing module of the electronic paper display driver determines at least one pixel to activate based on the received pen input information. The at least one pixel is updated independent of the display update rate of the electronic paper display. Active pixel state information is maintained separately for each pixel in real time until the pixel update is complete and the pixel is deactivated. In some embodiments, a future pixel to activate is determined based on the received pen input information. The future pixel is deactivated if pen input information is not received on the activated pixel for a predetermined amount of time.

The features and advantages described in the specification are not all inclusive and, in particular, many additional features and advantages will be apparent to one of ordinary skill in the art in view of the drawings, specification and claims. Moreover, it should be noted that the language used in the specification has been principally selected for readability and

instructional purposes and may not have been selected to delineate or circumscribe the disclosed subject matter.

BRIEF DESCRIPTION OF DRAWINGS

The disclosed embodiments have other advantages and features which will be more readily apparent from the detailed description, the appended claims and the accompanying figures (or drawings). A brief introduction of the figures is below.

FIG. (FIG.) **1** illustrates a cross-sectional view of a portion of an exemplary electronic paper display in accordance with some embodiments.

FIG. **2** illustrates a block diagram of a control system of the electronic paper display in accordance with some embodiments.

FIG. **3** illustrates software architecture of a pen tracking driver in the electronic paper display system in accordance with some embodiments.

FIG. **4** illustrates a flow chart of the main routine of the pen tracking driver in the electronic paper display system in accordance with some embodiments.

FIG. **5** illustrates a flow chart of the frame counter thread of the pen tracking driver in the electronic paper display system in accordance with some embodiments.

FIG. **6** shows a graphical representation of pen tracking timing of the electronic paper display system in accordance with some embodiments.

FIG. **7** illustrates a graphical representation of a method for motion prediction in accordance with some embodiments.

The figures depict various embodiments of the present invention for purposes of illustration only. One skilled in the art will readily recognize from the following discussion that alternative embodiments of the structures and methods illustrated herein may be employed without departing from the principles of the invention described herein.

DETAILED DESCRIPTION

The Figures (FIGS.) and the following description relate to preferred embodiments by way of illustration only. It should be noted that from the following discussion, alternative embodiments of the structures and methods disclosed herein will be readily recognized as viable alternatives that may be employed without departing from the principles of what is claimed.

As used herein any reference to "one embodiment," "an embodiment," or "some embodiments" means that a particular element, feature, structure or characteristic described in connection with the embodiment is included in at least one embodiment. The appearances of the phrase "in one embodiment" in various places in the specification are not necessarily all referring to the same embodiment.

Some embodiments may be described using the expression "coupled" and "connected" along with their derivatives. It should be understood that these terms are not intended as synonyms for each other. For example, some embodiments may be described using the term "connected" to indicate that two or more elements are in direct physical or electrical contact with each other. In another example, some embodiments may be described using the term "coupled" to indicate that two or more elements are in direct physical or electrical contact. The term "coupled," however, may also mean that two or more elements are not in direct contact with each other, but yet still co-operate or interact with each other. The embodiments are not limited in this context.

As used herein, the terms "comprises," "comprising," "includes," "including," "has," "having" or any other variation thereof, are intended to cover a non-exclusive inclusion. For example, a process, method, article or apparatus that comprises a list of elements is not necessarily limited to only those elements but may include other elements not expressly listed or inherent to such process, method, article or apparatus. Further, unless expressly stated to the contrary, "or" refers to an inclusive or and not to an exclusive or. For example, a condition A or B is satisfied by any one of the following: A is true (or present) and B is false (or not present), A is false (or not present) and B is true (or present) and both A and B are true (or present).

In addition, use of the "a" or "an" are employed to describe elements and components of the embodiments herein. This is done merely for convenience and to give a general sense of the invention. This description should be read to include one or at least one and the singular also includes the plural unless it is obvious that it is meant otherwise.

Reference will now be made in detail to several embodiments, examples of which are illustrated in the accompanying figures. It is noted that wherever practicable similar or like reference numbers may be used in the figures and may indicate similar or like functionality. The figures depict embodiments of the disclosed system (or method) for purposes of illustration only. One skilled in the art will readily recognize from the following description that alternative embodiments of the structures and methods illustrated herein may be employed without departing from the principles described herein.

Device Overview

FIG. (FIG.) **1** illustrates a cross-sectional view of a portion of an exemplary electronic paper display **100** in accordance with some embodiments. The components of the electronic paper display **100** are sandwiched between a top transparent electrode **102** and a bottom backplane **116**. The top transparent electrode **102** is a thin layer of transparent material. The top transparent electrode **102** allows for viewing of microcapsules **118** of the electronic paper display **100**.

Directly beneath the transparent electrode **102** is the microcapsule layer **120**. In one embodiment, the microcapsule layer **120** includes closely packed microcapsules **118** having a clear liquid **108** and some black particles **112** and white particles **110**. In some embodiments, the microcapsule **118** includes positively charged white particles **110** and negatively charged black particles **112**. In other embodiments, the microcapsule **118** includes positively charged black particles **112** and negatively charged white particles **110**. In yet other embodiments, the microcapsule **118** may include colored particles of one polarity and different colored particles of the opposite polarity. In some embodiments, the top transparent electrode **102** includes a transparent conductive material such as indium tin oxide.

Disposed below the microcapsule layer **120** is a lower electrode layer **114**. The lower electrode layer **114** is a network of electrodes used to drive the microcapsules **118** to a desired optical state. The network of electrodes is connected to display circuitry, which turns the electronic paper display "on" and "off" at specific pixels by applying a voltage to specific electrodes. Applying a negative charge to the electrode repels the negatively charged particles **112** to the top of microcapsule **118**, forcing the positively charged white particles **110** to the bottom and giving the pixel a black appearance. Reversing the voltage has the opposite effect—the positively charged white particles **112** are forced to the surface, giving the pixel a white appearance. The reflectance (brightness) of a pixel in an EPD changes as voltage is applied. The amount the pixel's reflectance changes may depend on both the amount of voltage and the length of time for which it is applied, with zero voltage leaving the pixel's reflectance unchanged.

The electrophoretic microcapsules of the layer **120** may be individually activated to a desired optical state, such as black, white or gray. In some embodiments, the desired optical state may be any other prescribed color. Each pixel in layer **114** may be associated with one or more microcapsules **118** contained with a microcapsule layer **120**. Each microcapsule **118** includes a plurality of tiny particles **110** and **112** that are suspended in a clear liquid **108**. In some embodiments, the plurality of tiny particles **110** and **112** are suspended in a clear liquid polymer.

The lower electrode layer **114** is disposed on top of a backplane **116**. In one embodiment, the electrode layer **114** is integral with the backplane layer **116**. The backplane **116** is a plastic or ceramic backing layer. In other embodiments, the backplane **116** is a metal or glass backing layer. The electrode layer **114** includes an array of addressable pixel electrodes and supporting electronics.

System Overview

FIG. **2** illustrates a block diagram of a control system **200** of the electronic paper display **100** in accordance with some embodiments. The system includes the electronic paper display **100**, an input sensor panel **212**, a pen tracking driver **204**, a display controller **208** and a waveforms module **210**. In some embodiments, the display **100** includes the input sensor panel **212**. In some embodiments, the input sensor panel **212** is a touch screen sensor disposed on top of the display **100**. In other embodiments, the input sensor panel **212** is disposed beneath the display **100** like a Wacom EMR sensor.

For purposes of illustration, FIG. **2** shows the pen tracking driver **204** and display controller **208** as discrete modules. However, in various embodiments, any or all of the pen tracking driver **204** and display controller **208** can be combined. This allows a single module to perform the functions of one or more of the above-described modules.

The pen tracking driver **204** receives pen tracking data **202** as a pen or stylus comes in contact with input sensor panel **212**. The pen tracking driver **204** keeps track of the active pixels and maintains a frame counter for each pixel. More information regarding the functionality of the pen tracking driver **204** is provided below in the description of FIGS. **3-5**.

An active pixel buffer (not shown in this figure) receives information and stores controlling information. The active pixel buffer contains the pixel data directly used by the display controller **208**. More details regarding the active pixel buffer is provided below.

The display controller **208** includes a host interface for receiving information such as pixel data. The display controller **208** also includes a processing unit, a data storage database, a power supply and a driver interface (not shown). In some embodiments, the display controller **208** includes a temperature sensor and a temperature conversion module. In some embodiments, a suitable controller used in some electronic paper displays is one manufactured by E Ink Corporation. For example, a suitable controller is the METRONOME™ display controller manufactured by E Ink Corporation.

The waveforms module **210** stores the waveforms to be used during pen tracking on the electronic paper display. In some embodiments, each waveform includes 256 frames, in which each frame takes a twenty millisecond (ms) time slice and the voltage amplitude is constant for all frames. The voltage amplitude is either 15 volts (V), 0V, or −15V. In some embodiments, 256 frames is the maximum number of frames that can be stored in the active pixel buffer **304** (FIG. **3**) for a particular display controller. In some embodiments, the maximum number of frames is used to minimize the possible overhead of time gaps between repeatedly called display commands during a long stroke pen tracking.

During display updates, the three waveforms are indexed by the controller as follows. In some embodiments, each pixel has 8 bits; 4 bits being the pixel value of the current state and the other 4 bits being the pixel value of the next state. In some embodiments, only two values are used for each state of each pixel: 0x0 and 0xF in hexadecimal, representing the black state and white state, respectively. Provided below is list of the waveform index pairs of current and next pixel state values in hexadecimal, and the corresponding impulse voltage, and the represented state transition:

current=0x0, next=0xF, 15V, black to white;
current=0xF, next=0x0, −15V, white to black;
current=0x0, next=0x0, 0V, no change in pixel color; and
current=0xF, next=0xF, 0V, no change in pixel color.

When a white pixel is activated by the pen tracking, its next state in the frame buffer becomes black. Therefore, the waveform of −15V is applied on the pixel. On the other hand, if a pixel is not activated, then the 0V is applied on the pixel. The duration of the voltage addressing is determined by a frame counter for that pixel, a description of which is provided below.

FIG. **3** illustrates software architecture of a pen tracking driver **204** in the control system **200** in accordance with some embodiments. The software architecture includes a main routine **302**, an active pixel buffer **304**, three modules **306**, **308** and **310** and two data buffers **312** and **314**.

The three modules include an input sensor module **306**, a line drawing module **308** and frame counter module **310**. These modules are three threads that perform in parallel. The threads utilize two major data buffers: a sampling list **312** and a display list **314**. The sampling list **312** stores the screen touched points that are sampled by the input sensor and that have not been processed by the line drawing module **308**. The display list **314** keeps track of the active pixels that are being updated (blackened) by a display controller **208**. The display list **314** also maintains a frame counter for each pixel, which determines the duration of voltage addressing for each pixel.

The input sensor module **306** monitors the input sensor sample data buffer received from the input sensor panel **212** and adds new samples to the sample list. The input sensor module **306** receives pen tracking data **202** as the input sensor panel **212** of the electronic paper display **100** is touched. In some embodiments, the input sensor module **306** receives the pen tracking data **202** in the form of coordinates of the points touched on the input sensor. In some embodiments, the input sensor module **306** receives the pen tracking data **202** and converts the data into another readable form. The input sensor module **306** adds the pen tracking data **202** to the sampling list as the pen tracking data **202** is received.

The line drawing module **308** reads the pen tracking data **202** from the sampling list **312**. The line drawing module **308** uses the pen tracking data **202** to draw a line or curve between neighboring sample points. In some embodiments, Bresenham's line drawing algorithm is used to draw a line between each two neighboring sample points. Algorithms for drawing lines between two points are well understood by those skilled in the art of computer graphics and will not be described in more detail here.

During the line drawing process, each activated pixel is immediately updated in the active pixel buffer **304**, where, for example, a current state value of white (0xF) and a next state value of black (0) are written. The line drawing module **308** initiates the display update of the pixel by setting up that state of the pixel in the active pixel buffer **304**, therefore updating the information of the pixel with the desired state information. The line drawing module **308** sends information associated with which pixels are to be updated. The active pixel buffer **304** stores this information, which includes information associated with the direction that the image should be going. In other words, the active pixel buffer **304** stores information to help determine which pixel to activate to allow for pixel by pixel update based, in part, on the data received from the line drawing module **308**.

During the line drawing, each drawn pixel is immediately updated in the active pixel buffer **304**. Meanwhile, the line drawing module **308** also adds each pixel on the line to the display list **314** and sets the frame counter for the pixel using a predefined number. For example, in some embodiments, the line drawing module **308** also each pixel on the line to the display list **314** and sets the frame counter a value of fifteen frames. The processed sample data points are then removed from the sampling list **312**.

The frame counter module **310** repeatedly scans the display list **314** and checks the frame counter for each pixel in the list. The frame counter module **310** relays information regarding the duration of the pixel update to the active pixel buffer **304**. In other words, the frame counter module **310** keeps track of the frame counter for each pixel update. When the frame counter equals zero, this indicates that the pixel update is complete and needs to be reset in the active pixel buffer **304**.

FIG. **5** illustrates a flow chart of the frame counter module **310** of the pen tracking driver **204** in the electronic paper display system in accordance with some embodiments. The frame counter module **310** scans **502** the display list **314** and checks the frame counter for each pixel in the display list **314**. A determination **504** is made as to whether the scan has reached the end of the display list **314**. If the end of the display list **314** has been reached (**504**—Yes), the frame counter module **310** waits for a predetermined interval of time and continues to scan **502** the display list **314**. In some embodiments, the frame counter module **310** waits for 20 ms until it continues to scan the display list **314**. This allows for the display update to execute for a portion of time after the frame counter is decreased.

If the end of the display list **314** has not been reached (**504**—No), a determination **506** is made as to whether the frame counter is equal to zero. If the frame counter is not equal to zero (**506**—No), the frame counter is decreased **512** by one. If the frame counter is equal to zero, this means that the pixel has completed its transition from one state to the next. The index is then increased **510** by one and frame counter module **310** continues to determine **504** whether it has reached the end of the display list.

If the frame counter is equal to zero (**506**—Yes), the pixel value in the active pixel buffer **304** is reset **514** since the pixel has completed its transition from one state to the next, for example, from white to black. As an example, a current pixel value of zero and a next pixel value of zero are written to the active pixel buffer **304**. A voltage of zero is applied to the pixel update until the next change occurs. The deactivated pixel is removed **516** from the display list **314**.

In some embodiments, the predefined interval of time and frame counter initial value can be selected to achieve the desired state of the pen tracking pixels, depending on the application requirements, typically the contrast and update speed. At a given time interval, the larger the frame counter initial values are, the longer the duration of update. However, when the frame counter initial value is large enough, the updated pixels end up as saturated black. If saturation is not desired, the frame counter initial value should be set small.

Referring back to FIG. **3**, the main routine **302** repeatedly checks the display list **314** and if the display list **314** is not empty, a display command is issued to the display controller **208**. FIG. **4** illustrates a flow chart of the main routine **302** of the pen tracking driver **204** in the electronic paper display system in accordance with some embodiments. The main routine **302** repeatedly checks the display list **314** and if the display list **314** is not empty, a display command is issued to the display controller **208**.

The main routine **302** is initialized **402** and determines **404** whether the display list **314** is empty. If the display list **314** is empty (**404**—Yes), it continues to check **315** the display list **314**. If the display list **314** is not empty (**404**—No), a display command is issued **406** to the display controller **208**. In other words, the main routine **302** keeps the display controller **208** active as the main routine **302** constantly provides information to the display controller **208** as the information is received.

FIG. **6** illustrates a graphical representation of pen tracking timing of the electronic paper display **100** in accordance with some embodiments. In some embodiments, each waveform includes 256 frames and display updates **602** for the 256 voltage frames occur at an update rate of 20 ms. The input sensor sampling **604** is performed at a sampling rate of 20 ms. The line drawing and active pixel buffer updates **606** also occur at an update rate of 20 ms. In other words, as shown in the line pixel display updates **608**, line pixel L**1** update starts when initiated and line pixel L**2** update occurs 20 ms after the initiation of line pixel L**1** update. Line pixel L**3** then occurs 20 ms after the initiation of line pixel L**2** update, and so on. This pixel by pixel update allows for fast pen tracking on electronic paper displays. Pixels can be individually updated at a very high rate, independent of the entire display being updated.

In an alternate embodiment, motion prediction can be used to determine future pixels to be updated to achieve both high contrast and fast pen tracking update. Each of these future pixels can be activated for updating several frames earlier than the time when it is actually touched by the pen. Later on, if an activated pixel is not actually touched by the pen, the pixel updating is then immediately turned off, or deactivated. This idea is based on the fact that the reflectance time response of some electronic paper displays has highly non-linear characteristics.

The non-linearity of the reflectance-time response indicated that the display brightness change gets smaller when the gray state is saturated in either direction, black or white. This implies that earlier start of update would not be noticeable by the human eye until a certain time period later. Therefore, motion prediction could be used to save some time for the entire state transition. The more non-linear near the saturation zone, the more time could be saved by using motion prediction.

The motion prediction can be performed during the line drawing process. The line drawing algorithm predicts the pen moving direction for the next few steps and activates the display update for the pixels in a certain shape of region that lies in the predicted moving direction. The prediction can be either line or curvature based, depending on the specific application.

FIG. **7** illustrates a graphical representation of a method for motion prediction in accordance with some embodiments. As shown in FIG. **7**, line **702** represents a line drawn on an electronic paper display. In FIG. **7** line **702** is at current point **704**, which is where the input sensor is touching the display. As the pen tracking moves toward the future point **706**, the pixels within the region **708** are activated for a predetermined period of time. For example, in some embodiments, the pixels within the region **708** are activated for 60 ms. If the pixel is not actually activated (not actually touched by the pen tracking movement) after the predetermined period of time, the pixel is deactivated or turned off. The rate at which this occurs allows for the appearance of fast pen tracking when pen tracking is being performed on an electronic paper display. Deactivating a pixel means restoring it to the original state by driving it in reverse using the opposite voltage for the same amount of time it was originally driven when it was activated.

Upon reading this disclosure, those of skill in the art will appreciate still additional alternative structural and functional designs for a system and a process for pen tracking and low latency updates on an electronic paper display through the disclosed principles herein. Thus, while particular embodiments and applications have been illustrated and described, it is to be understood that the disclosed embodiments are not limited to the precise construction and components disclosed herein. Various modifications, changes and variations, which will be apparent to those skilled in the art, may be made in the arrangement, operation and details of the method and apparatus disclosed herein without departing from the spirit and scope defined in the appended claims.

What is claimed is:

1. A method for activating pixels on an electronic paper display that updates at a predetermined display update rate, comprising:

receiving pen input information for at least one current pixel of the electronic paper display;

determining the at least one current pixel to activate based on the pen input information for the at least one current pixel;

activating the at least one current pixel of the electronic paper display independent of the display update rate of the electronic paper display;

predicting a direction of the pen input to determine at least one future pixel of the electronic paper display to activate based on the pen input information for the at least one current pixel;

activating the at least one future pixel based on the pen input information for the at least one current pixel; and

deactivating the activated future pixel after a predetermined amount of time in response to an absence of receiving pen input information for the activated future pixel.

2. The method of claim **1**, further comprises activating the at least one future pixel by applying a voltage to the at least one future pixel.

3. The method of claim **2**, further comprises deactivating the activated future pixel by reversing the applied voltage to the activated future pixel.

4. The method of claim **1**, further comprising:

activating a region of the electronic paper display based on the pen input information for the at least one current pixel; and

deactivating the activated region of the electronic paper display in response to, after the predetermined amount of time, an absence of receiving pen input information for the activated region.

5. The method of claim **1**, wherein the pen input information is received on a touch sensor display.

6. The method of claim **1**, further comprising:

maintaining active pixel information for each current pixel.

7. The method of claim **6**, wherein the maintaining active pixel information includes maintaining a display list for each current pixel.

8. The method of claim **6**, wherein the maintaining active pixel information includes maintaining a frame counter for each current pixel.

9. A system for activating pixels on an electronic paper display that updates at a predetermined display update rate, comprising:

means for receiving pen input information for at least one current pixel of the electronic paper display;

means for determining the at least one current pixel to activate based on the pen input information for the at least one current pixel;

means for activating the at least one current pixel of the electronic paper display independent of the display update rate of the electronic paper display;

means for predicting a direction of the pen input to determine at least one future pixel of the electronic paper display to activate based on the pen input information for the at least one current pixel;

means for activating the at least one future pixel based on the pen input information for the at least one current pixel; and

means for deactivating the activated future pixel after a predetermined amount of time in response to an absence of receiving pen input information for the activated future pixel.

10. The system of claim **9**, further comprising:

means for activating the at least one future pixel by applying a voltage to the at least one future pixel.

11. The system of claim **10**, further comprising:

means for deactivating the activated future pixel by reversing the applied voltage to the activated future pixel.

12. The system of claim **9**, further comprising:

means for activating a region of the electronic paper display based on the pen input information for the at least one current pixel; and

means for deactivating the activated region of the electronic paper display in response to, after the predetermined amount of time, an absence of receiving pen input information for the activated region.

13. The system of claim **9**, wherein the pen input information is received on a touch sensor display.

14. The system of claim **9**, further comprising:

means for maintaining active pixel information for each current pixel.

15. The system of claim **14**, wherein the means for maintaining active pixel information includes maintaining a display list for each current pixel.

16. The system of claim **14**, wherein the means for maintaining active pixel information includes maintaining a frame counter for each current pixel.

17. An apparatus for pen tracking on an electronic paper display that updates at a predetermined display update rate, comprising:

one or more processors;

an input sensor module for receiving pen input information for at least one current pixel of the electronic paper display; and

a line drawing module stored on a memory and executable by the one or more processors, the line drawing module coupled to the input sensor module and for determining the at least one current pixel to activate based on the pen input information for the at least one current pixel, predicting a direction of the pen input to determine at least one future pixel of the electronic paper display to activate based on the pen input information for the at least one current pixel and for activating the at least one current pixel of the electronic paper display independent of the display update rate of the electronic paper display;

a third module stored on the memory and executable by the one or more processors, the third module coupled to the line drawing module for activating the at least one future pixel based on the pen input information for the at least one current pixel; and

a fourth module stored on the memory and executable by the one or more processors, the fourth module coupled to the line drawing module for deactivating the activated future pixel after a predetermined amount of time in response to an absence of receiving pen input information for the activated future pixel.

18. The apparatus of claim **17**, wherein the third module activates the at least one future pixel by applying a voltage to the at least one future pixel.

19. The apparatus of claim **18**, wherein the fourth module deactivates the activated future pixel by reversing the applied voltage to the activated future pixel.

20. The apparatus of claim **17**, wherein the third module further activates a region of the electronic paper display based on the pen input information for the at least one current pixel and the fourth module further deactivates the activated region of the electronic paper display in response to, after the predetermined amount of time, an absence of receiving pen input information for the activated region.

21. The apparatus of claim **17**, wherein the pen input information is received on a touch sensor display.

22. The apparatus of claim **17**, further comprising:

an active pixel buffer for maintaining active pixel information for each current pixel.

23. The apparatus of claim **22**, wherein the active pixel buffer for maintaining active pixel information includes maintaining a display list for each current pixel.

24. The apparatus of claim **22**, wherein the active pixel buffer for maintaining active pixel information includes maintaining a frame counter for each current pixel.

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